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Human-Robot Interface Controller Usability for Mission Planning on the Move

by Christopher Stachowiak, Ellen Haas, Theo Feng, and Krishna Pillalamarri

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Human Research and Engineering Directorate, ARL

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14. ABSTRACT
Effective operator control interfaces for unmanned air and ground vehicles (UAVs, UGVs) are essential in both the mission planning phase and any intervention phase. A complicating element of operator control is that it is not always performed while the vehicle is still or idle; it may occur while the operator is in a moving vehicle on cross-country or relatively undeveloped (e.g., gravel road) terrain. The primary objective of this study was to determine the usability of three different computer game control devices—trackball, joystick, and game pad—for U.S. Army human-robotic interface tasks performed in a moving Army vehicle. The second objective was to determine the extent to which vehicle operation in different conditions (baseline engine idle, gravel roads, and cross-country terrain) affects the usability of the different controllers.

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1. Introduction

Unmanned ground and air vehicles (UGVs and UAVs) embody a critical capability of future U.S. Army systems and will be used for force projection and as force multipliers. They are expected to operate in a semiautonomous fashion, in which an operator will lay out a mission plan for the vehicle to execute with little or no operator interaction; the operator's function will be to monitor the progress of the unmanned systems. If the situational demands exceed the capabilities of the vehicle, the operator will need to intervene to complete the mission by either changing the mission plan or by assuming direct control of the vehicle by teleoperation until the vehicle can resume semiautonomous operation.

Effective operator control interfaces for UAVs and UGVs are essential in both the mission planning phase and any intervention phase. A complicating element of operator control is that it is not always performed while the vehicle is still or idle; it may occur while the operator is in a moving vehicle on cross-country or relatively undeveloped (e.g., gravel road) terrain. Throughout years of U.S. Army Research Laboratory (ARL) workstation development for demonstrations and experiments based on operations on the move (OTM), it has been demonstrated that operation of conventional computer control devices in a moving vehicle is challenging at best. Vehicle roll, pitch, yaw, and vibration during travel can make common cursor controllers like the mouse difficult to impossible to use. In fact, the mouse was so difficult to operate OTM in this vehicle that it was immediately discarded and replaced with a trackball during the demonstration and development phases of outfitting the vehicle. One example is the use of a handheld trackball during the Office of the Secretary of Defense Robotics DEMO II from 1992 to 1996. Human-robotic interface (HRI) devices, such as those needed for control of unmanned systems, must be researched in these challenging environments to optimize operator performance.

This study was run to determine the usability of control devices for the in-vehicle control of unmanned robotic systems. Control devices commonly known as console controllers or game pads have proven successful for use in commercial computer video games. The goal of this study was to benefit the Army by gathering and using Soldier performance data for the use of common computer controllers, (i.e., joystick and trackball) and the console controller, to establish performance baselines for computer control devices in Army vehicles moving on various terrain conditions. A second goal was to provide information that may allow the Army to leverage the large controller design investment already made by the world-wide gaming industry to improve the Soldier/controller interface in Army control systems and provide design guidelines for controllers in Army OTM applications.

As a part of the Distributed Aperture System Army Technology Objective effort, a literature search for information regarding the usability of console game controllers revealed virtually no research regarding the use of controller devices in moving environments such as military vehicles. Limited examples were found, such as an evaluation of a handheld keyboard control (Ting and Hedge, 2001) that evaluated a unique, handheld, hybrid keyboard-game controller and found that it needed more refinement to be an alternative solution for Army keyboard and control tasks. The dearth of publicly available research is believed to result from the fact that any such information is proprietary to highly competitive commercial game companies. Nonetheless, the lack of evidence regarding the usefulness of game controllers is not a sufficient reason to eliminate the game controller as a possible control device for control systems used in moving vehicles. Game controllers and game pads have been used successfully in a variety of nonmilitary environments, including OTM automotive applications in vehicles such as minivans (Honda Odyssey Forum, 2011). Therefore, a video console game controller or game pad may be a very good alternative control device to the joystick for a mobile OTM military system.

The game controller has become a commonly used electronic device familiar to many potential users (Console Wars, 2006; Game Controller, 2006), which may provide positive transfer of training to military control systems. Game control devices may provide several advantages for use in moving vehicle environments. To be effective, conventional control devices such as a mouse, keyboard, or joystick need to be mounted or placed on a surface, such as a desktop for a mouse. One advantage of the game controller is that it is a self-contained, hand-held device, i.e., no mounting is necessary for use. Another advantage is that the game controller is portable and can easily be passed from one Soldier to another, without regard to their seating position or nearby fixtures, to promote interaction and easy use during mobile operations. The game controller is also relatively small and can be easily stowed in a carrier when not in use; this means, of course, that it also can be more easily misplaced than a mounted controller.

Operators need to rely on stabilization points to brace their hands, wrists, and forearms when performing control tasks with conventional controls in moving vehicles or erratic movements occur. Another game controller advantage is that it is easily held in the hand, which eliminates the effects of large skeletal movements; the hand is the reference point of the controller, enabling the thumbs and forefingers to manipulate controller functions. This should help minimize erratic control movements caused by vehicle motion and vibration.

2. Research Objective

The primary objective of this study was to determine the usability of three different computer game control devices (trackball, joystick, and Xbox 360 Controller[*]) for Army HRI tasks performed in a moving Army vehicle. The second objective was to determine the extent to which vehicle operation in different conditions (baseline engine idle, gravel roads, and cross-country terrain) affects the usability of the different controllers.

Several hypotheses were developed. The first was that vehicle motion would negatively impact the ability of a user to operate all controllers for HRI mission planning and teleoperation tasks. The second hypothesis was that the Xbox controller would provide a performance advantage over the joystick and trackball on rough terrain because the hand-held device would be easier to stabilize against the body and enable the controls to be referenced to the operator's hand. The latter would allow more efficient use of the operator's thumbs and fingers, enabling more efficient control manipulation. The third hypothesis was that terrain types with a greater variation in surface would have a more significant effect on controller performance. Therefore, cross-country terrain was hypothesized to produce the greatest Soldier performance decrements from the baseline vehicle idle.

3. Method

3.1 Participants

The study engaged a total of 12 adults, ranging from 18 to 56 years of age. Participants were ARL civilians who volunteered during normal duty hours and were not compensated for their role in this study beyond their normal salary or wages. The participants were prescreened, and those selected reported a low susceptibility to motion or simulator sickness, no medical conditions that might be affected by motion, and normal visual functioning (including corrected vision) of 20/40 or better.

3.2 Apparatus

The apparatus consisted of a high-mobility, multipurpose, wheeled vehicle (HMMWV) with a mounted shelter, a workstation computer, control devices, and mission planning software.

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[*]Xbox 360 Controller is a registered trademark of Microsoft Corporation.

3.2.1 HMMWV

The HMMWV was equipped with a diesel engine, automatic transmission, and four-wheel drive. Figure 1 shows the HMMWV vehicle with shelter used in this study.

Figure 1. HMMWV with shelter.

As can be seen in figure 1, a hard-walled shelter was mounted on the rear portion of the HMMWV. The shelter, which has been bolted through its floor to structural components of the HMMWV, was equipped with two workstations and two seats (one each for the participant and experimenter). The seats were pedestal-mounted, forward-facing, high-backed seats with adjustments in vertical, lateral, and horizontal dimensions as well as rearward reclining, and were equipped with lap belts. For this study, the seats were adjusted for participant comfort and to allow a viewing distance of ~20 in to the workstation screen. The participant's workstation had an 18-in computer monitor, keyboard, joystick, X-Box controller, and trackball controller. Between the seats and the monitors, 28 in from the floor, was an 11-in-deep keyboard shelf with a 10° slope that runs the width of the vehicle. This shelf was where the joystick and trackball were mounted for the experiment. The X-Box controller is hand-held, so it was not mounted.

During the experiment, the participants rode in the left seat. The experimenter rode on the seat next to the participant, and thus had immediate visual and physical access to the participant. Figure 2 shows a schematic diagram of the shelter interior.
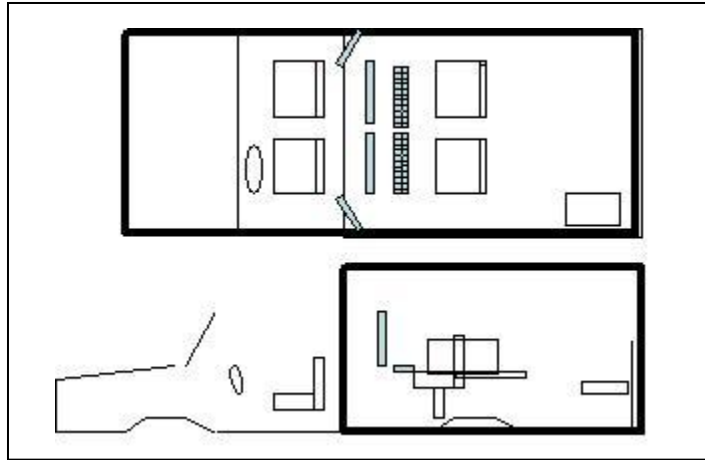
Figure 2. Representation of the interior layout of the HMMWV
shelter. Top is the overhead view and bottom is the
driver-side view.

The interior of the vehicle was lit by ceiling-mounted light fixtures. Ventilation to the interior was provided by a roof-mounted air conditioner and heater unit. A three-foot step ladder attached to the shelter was used for shelter ingress and egress. For emergency egress, there was a permanently mounted ladder beside the outer door. Emergency egress procedures were covered in the participant safety training. Movement into and out of the workstation seats was performed via the 16-in (minimum) passageway between the seats or between the seats and the shelter walls.

Several safety measures were adopted. The experimenter and participant were able to maintain primary communication with the vehicle driver via radio in case of emergency. Secondary communication was via a button mounted on the wall to the left of the experimenter; if pressed, a red light on the driver's console was activated and the driver would immediately come to a controlled stop. The vehicle driver was licensed and qualified to drive the HMMWV. Before the study, the vehicle was checked by experienced vehicle safety personnel from the Aberdeen Test Center Vehicle Safety Office, who inspected the vehicle exterior and interior to ensure that it was safe for participants and experimenters.

During this study, vehicle ride dynamics were measured with an accelerometer to quantify vehicle vibration characteristics. The accelerometer was noninvasive to the participant; the accelerometer was embedded within a rubber pad that rested upon the participant's seat pad. Ride dynamics were collected to compare ride characteristics between participants as needed, as well as to compare ride characteristics between past and future experiments.

3.2.2 Workstation Computer

The participant's workstation computer was a ruggedized Z Microsystems Intel-based system with an Intel motherboard, 2.2-GHz P4 CPU, 512 MB of RAM, and an ASUS V9180 Magic

GeForce 4 MX440, 64-MB video card. The displays were Computer Dynamics rack-mounted, flat-panel, touch-screen displays with 1280 × 1024 pixel resolution. These displays featured an 18-in, active-matrix, thin film transistor liquid crystal display with 170° viewing cone and 235-nit (candela per square meter) brightness. The display also featured 350:1 contrast ratio and 25-ms typical pixel response time.

2.2.3 Control Devices

The three controller devices used in this experiment were: (1) a Microsoft Xbox 360 Controller for Windows Game Pad (referred to as Xbox), (2) a CH Products IP desktop joystick (with three degrees of freedom) (referred to as joystick), and (3) a Microsoft Trackball Explorer (referred to as trackball). These controllers are seen in figures 3–5. The Xbox was selected as the representative game pad because of its ability to interface to Windows. The joystick was selected because it most closely resembled the joystick used by the ARL Robotics Program Office. The trackball was chosen because of its successful operation in other ARL Human Research and Engineering Directorate (HRED) HMMWV studies (e.g., Haas and Stachowiak, 2007).

Figure 3. Microsoft Xbox 360 controller for Windows.

Figure 4. CH products IP desktop joystick.

Figure 5. Microsoft Trackball Explorer.

3.2.4 Mission Planning Software

Custom software was designed to present cursor-control HRI mission planning tasks and to collect time and error data associated with experimental tasks. Four cursor-based mission planning tasks (point-to-point move and object selection; drag and drop; select and hold; and mouse drag area selection) were chosen because they incorporated elements of basic control functions and represented common unmanned vehicle mission planning tasks associated with the Robotics Collaborative Technology Alliance (RCTA) Tactical Control Unit (TCU). The software was designed to emulate the RCTA TCU in appearance and present representative robotics usability tasks, while collecting time and accuracy data on those tasks.

The RCTA TCU is a map-based control and display system for Soldiers to plan and monitor unmanned vehicle missions. Figure 6 shows the study's custom software screen, which is based on the TCU.
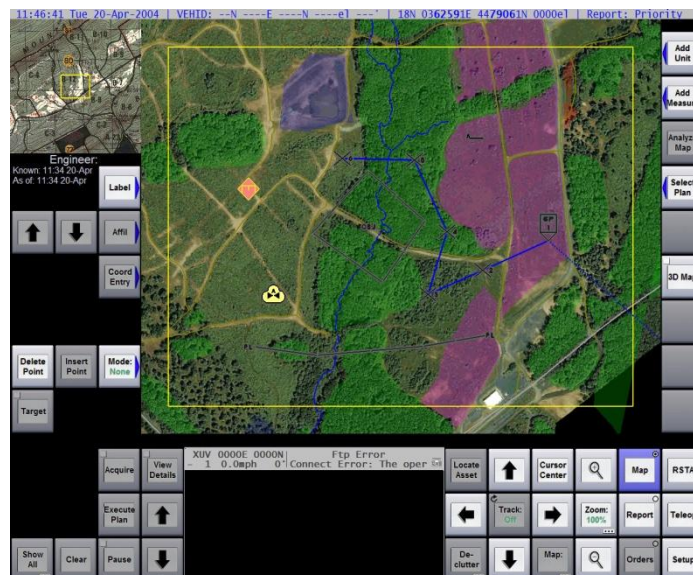

Figure 6. Example of custom software screen.

3.3   Questionnaires

Questionnaires consisted of a demographics and health screening questionnaire, symptom questionnaire, on-the-spot workload questionnaire, and evaluation questionnaire. The demographics and health screening questionnaire was given at the beginning of each test day. The symptom questionnaire, adapted from Gianaros et al. (2001) was given at the beginning of each day and after each condition to determine the participant's physical motion sickness symptoms at that moment in time. After data collection trials, the participant provided an on-the-spot single workload rating estimate (Hart and Bortolissi, 1984; Moray et al., 2006) in which he or she verbally assigned a number between 1 and 10 to describe the workload associated with that task, with 1 representing very low and 10 representing very high workload estimates. The evaluation questionnaire was given after each movement condition.

3.4   Test Course

This study was conducted at the ARL Ground Vehicle Experimental Course (GVEC) at Aberdeen Proving Ground, MD. The course is ~4 acres in size. The specific vehicle paths were a combination of secondary (gravel road) and off-road (cross-country) courses. The gravel road was flat and encircled the cross-country course, which was mostly flat, with several small hills and ridges to create vehicle pitch, roll, and yaw motion. The course was surrounded by "jersey barriers" to prevent people or animals from straying onto the course and prevent the HMMWV from leaving the course. Vehicle speed on all courses was controlled by a qualified HRED driver, and was generally between 10 and 15 mph. A trailer on the course served as the experiment base, data collection area, and participant rest area. The trailer was separated from the active part of the course by a ditch and a line of jersey barriers. Attached to the trailer was an observation deck.

3.5   Ride Quality of HMMWV on Test Course

Ride quality data was collected using a seat pad accelerometer, installed in the participant's seat, and an Army Test Center advanced distributed modular acquisition system (ADMAS) data collection system. Vehicle vibration crest factor (the peak amplitude of the waveform divided by the root mean square amplitude value) was derived from accelerometer recordings for each movement session to characterize the ride quality. Crest factor is a single value used to describe the amplitude of vibration in each movement session.

Table 1 contains the root mean square amplitude (RMSA) and crest factor for each terrain (ISO 2631-1, 1997). The RMSAs and crest factors indicate that participants' ride quality deteriorated as they experienced idle, gravel, and cross-country conditions, in that order.

Table 1. Ride quality as described by root mean square amplitude (RMSA) and crest factor (CF) for seat pad vertical, translational, and longitudinal accelerations (in gs) for each terrain.

	Idle		Gravel		Cross-Country	
	RMSA	**CF**	**RMSA**	**CF**	**RMSA**	**CF**
Seat pad vertical acceleration	0.026	5.276	0.142	4.075	0.191	29.609
Seat pad translational acceleration	0.018	3.101	0.088	4.529	0.157	30.717
Seat pad longitudinal acceleration	0.043	2.183	0.072	4.186	0.156	36.581
Combined acceleration $\sqrt{x^2 + y^2 + z^2}$	0.053	6.498	0.182	7.392	0.292	56.199

3.6   Procedure

The order of events in this study is described in table 2. One participant was tested at a time. Participants were taken to the GVEC trailer, where they were given a volunteer agreement affidavit that described the study and possible risks. They were informed that they might withdraw from the experiment at any time or for any reason without reprisal. Each participant signed the consent form and was given a copy of the signed form, which included points of contact. Participants were screened for self-reported health and vision conditions, and susceptibility to simulator and motion sickness. Participants who met the experimental criteria filled out the volunteer agreement affidavit and the demographics and health screening and symptom questionnaires.

Table 2. Order of events.

Order	Event	Approximate Time (min)
1	Consent form	5
2	Demographic and health screening questionnaire; Symptom questionnaire (baseline)	5
3	Task training	30
4	Break; Symptom questionnaire	15
5	Movement condition I Controller 1 task, On the spot workload evaluation; Controller 2 task, On the spot workload evaluation; Controller 3 task, On the spot workload evaluation	30
6	Symptom questionnaire; Evaluation questionnaire	10
7	Break; Symptom questionnaire	15
8	Movement condition II Controller 1 task, On the spot workload evaluation; Controller 2 task, On the spot workload evaluation; Controller 3 task, On the spot workload evaluation	30
9	Symptom questionnaire; Evaluation questionnaire	10
10	Break; Symptom questionnaire	15
11	Movement condition III Controller 1 task, On the spot workload evaluation; Controller 2 task, On the spot workload evaluation; Controller 3 task, On the spot workload evaluation	30
12	Symptom questionnaire; Evaluation questionnaire	10
13	Wait/recovery period	20

Note: Approximate total: 3.75 h.

After the initial questionnaires were filled out, the participant was then taken to the HMMWV shelter while the vehicle engine was in idle and received training on the study set-up, scenario, and specific tasks. Each participant was familiarized with the vehicle, particularly safety and emergency egress procedures. The participant also learned how to provide on-the-spot single workload rating estimates. After this, the participant learned how to perform the experimental tasks (point-to-point move and selection; select and hold; drag and drop; and mouse-drag area selection) with the experimental controller for that condition. Time and error data was automatically collected by the software. A description of these tasks follows:

1. Point-to-point move and selection of objects involved using the control device to select a button on the screen, move the cursor to a target icon on the screen, select the icon, move to a second button, and select it. Time and accuracy were recorded. This task emulated a target acquisition task in which targets were deleted. The "next" button was selected (clicked on) to start the task; the curser was moved to a target icon, which was then selected; the curser was then moved to the "delete" target button to complete the task. Time was measured from the click of the "next" button until the click of the "delete" button at the end of each selection. Errors included clicking the background or wrong buttons instead of the target.

2. Select and hold involved moving the cursor to an icon, pushing the controller button to select the icon, and holding the button. If it took multiple pushes of the controller button to complete the task, it was considered an error. This task emulated a target acquisition task in which a target icon was moved into a "target zone" by selecting a directional arrow button and held; the target moved in the direction of the arrow as long as the arrow button was depressed. Each target movement required the use of two arrow buttons; hold time was measured from the "mouse down" time the arrow button was clicked until the "mouse up" time the arrow button was released. Errors included multiple clicks on an arrow button instead of a hold and click elsewhere on the screen.

3. Drag and drop involved moving the cursor to an icon, pushing a button to select the icon, and then holding the button while dragging the icon to a predetermined position on the screen. Upon reaching the predetermined position, the select button was released to drop the icon. This task emulated a target acquisition task in which a target icon was moved into a "target zone" by selecting and dragging the target icon to the "target zone." Time was measured from the "mouse down" time the icon was clicked until the "mouse up" time when the icon was dropped in the "target zone" by releasing the button. Errors included clicking the background instead of the target and when the icon was dropped outside of the target zone.

4. Mouse-drag area selection involved moving the cursor to a position on the screen in a text box, pushing a button to put the cursor into "select mode," then dragging the cursor to select all of the text in the text box except for the first character. This task emulated a mission planning text selection task, and required a great deal of dexterity to position the cursor between letters of text. The "next" button was selected (clicked on) to start the task; the text was then selected in a text box by the click, drag, and release method; then a clear button was selected to end the task. Time was measured from the click of the "next" button until the click of the "clear" button at the end of each selection. Errors included selection of text instead of the indicated area.

The participants executed the controller tasks in a software training mode. The training consisted of 20 repetitions of each task with each controller. After each training task with each controller, the participant was asked if they would like to receive more training, and were permitted more training until they felt competent in the performance of that task.

After training, experimental conditions were presented to each participant. Each task was presented 10 times for each controller within one movement condition (engine idle, gravel road, or cross-country terrain). Each movement condition lasted for ~30 min. Since three controllers were used in each movement condition, the participant performed a total of 120 experimental trials (10 sequential repetitions × 4 tasks × 3 controllers) in each movement condition. The participant had a short break (15–30 min) at the GVEC trailer between each movement condition.

After each movement condition, the participant was asked if he or she would like to continue participation in the remaining conditions (if there were any). If they agreed to continue, the trials continued as planned, beginning with the next experimental condition. If any participant did not wish to continue, the trials were abandoned and the experiment terminated for that subject. If the participant agreed to continue, he or she was specifically reminded that they could end the trial at any time. If the participant experienced any form of sickness during or after the experiment, he or she was permitted to recuperate under the supervision of study personnel.

As can be seen in table 1, before each movement condition, the participant filled out a symptom questionnaire   Between blocks of controller tasks, the also participant provided an on-the-spot single workload rating estimate. After each movement condition, the participant completed a symptom questionnaire and an evaluation questionnaire.

After completing the last task in the last movement condition, the experiment ended and the participant was brought to the GVEC trailer, where he or she completed the final evaluation questionnaire and symptom questionnaire. The participant was then told to remain at the test site for at least 30 min after the last trial, or until they had minimal symptoms, and was told not to drive until he or she had been free of dizziness or vertigo for at least 1 h. Just prior to dismissal from the experimental site, the participants were asked to complete a final symptom questionnaire to document their symptom state.

Time and error data in each condition were automatically collected by the data measurement software.

3.7   Experimental Design

The treatment structure for all controller tasks was a 3×3 within-subjects factorial design.

3.7.1 Independent Variables

The independent variables were as follows:

1. *Controller type* was a within-participant variable. The three categories of controller were:

   a. Microsoft Xbox 360 Controller for Windows Game Pad

   b. CH Products IP desktop joystick

   c. Microsoft Trackball Explorer

2. *Movement Condition* was a within-participant variable. The three categories of movement condition were:

   a. Vehicle at a stop, engine idling

   b. Vehicle traveling over cross-country terrain at 8–12 mph

   c. Vehicle traveling over gravel road at 10–15 mph

Movement conditions were assigned to participants by means of a double reverse, Latin Square design. The Latin Square was counterbalanced with respect to order of the treatments to ensure that each treatment was administered first, second, and last, and no treatment consistently followed another. Part way through the experiment, movement order was changed so that the cross-country movement condition would occur last for each subject, with the first two conditions counterbalanced with the original Latin Square. This change occurred because a large proportion of participants became ill during the cross-country condition and dropped out of the experiment. This change in presentation order was made to retain as many participants as possible.

The order in which each controller was assigned to each of the three movement conditions for each participant was counterbalanced with three double reverse, Latin Squares to ensure that each controller was administered first, second, and last, and that no controller consistently followed another.

3.7.2 Dependent Variables

The four experimental tasks performed during each condition were click and hold, drag and drop, point-to-point, and text select. For the click and hold task, the elapsed time and number of controller clicks to complete the task were obtained. Data for the drag and drop task were

the elapsed time to complete each task, number of clicks, and number of missed drags. The point-to-point task data were time to select the target, number of errors, and time to delete the target. For the text select task, data were time to select the target text and number of characters selected within the target text.

3.8 Data Analysis

Where response time data were positively skewed, a natural log transformation was performed to give the data a normal distribution (Cleveland, 1984). For all dependent variables, data were analyzed using separate analyses of variance (ANOVA). The ANOVAs were run using an SPSS Linear Mixed Model Analysis.

As previously noted, because many participants became ill after cross-country terrain, the order of presentation of terrain was changed part way through the study to permit the retention of participants. Thus, cross-country terrain was presented as the last terrain condition for 10 out of 12 participants. Because the order of terrain presentation was not counterbalanced, a statistical analysis was performed to take this into account. In addition to the controller and terrain variables, two order variables (order of presentation of terrain and order of presentation of controller) and a variable for sequence of terrain presentation (terrain sequence) were used in the statistical analysis to account for order of terrain presentation. The SPSS Linear Mixed Model procedure was run using terrain, terrain order, terrain sequence, controller, controller order, and terrain x controller as fixed effects. Random effects used were sequence within subject and terrain x terrain order x sequence within subject.

Interactions between the random and fixed effect factors were used as error terms for testing hypotheses about the fixed effect factors. Effects showing a probability value p greater than 0.05 were not considered statistically significant. The least significant difference post hoc test was performed at $p \leq 0.05$, but only if the corresponding test is statistically significant at the 0.05 level.

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4. Results

4.1 Click and Hold

4.1.1 Elapsed Time

The SPSS mixed model ANOVA performed on the log-transformed data indicated significant main effects for terrain (F = 17.59, p = 0.00) and controller (F = 3.02; p = 0.05). There were no other significant main effects or interactions. Post hoc testing indicated that there was a significant difference between each terrain, with cross-country terrain having the highest elapsed

time (11.58 ± 5.6 s mean ± s.d. reported throughout), gravel having a significantly lower elapsed time (9.69 ± 4.92 s), and idle engine having the lowest elapsed time (9.47 ± 4.10 s) for the click and hold task.

The post hoc test on the transformed controller data indicated that mean elapsed time was shortest for the trackball (9.70 ± 4.11 s), with no significant difference between the Xbox (10.52 ± 5.25 s) and the joystick (10.38 ± 5.43 s).

4.1.2 Number of Clicks

The ANOVA indicated significant main effects for controller (F = 9.41; p = 0.00), with no other significant main effects or interactions. The post hoc test indicated that the mean number of clicks required for the joystick (2.65 ± 1.25) was significantly lower than that required by the Xbox (2.87 ± 1.25) and trackball (3.08 ± 1.83) controllers. There was no significant difference between the trackball and Xbox controllers.

4.2   Drag and Drop

4.2.1 Elapsed Time

The ANOVA performed on the transformed data indicated a significant interaction effects for terrain x controller (F = 6.27; p = 0.00), and significant main effects for terrain (F = 25.96; p = 0.00) and for controller (F = 28.11; p = 0.00).

A post hoc test on the terrain x controller data (shown in figure 7) indicated that on idle and gravel terrain, there were significant differences between all controllers. The trackball provided a significantly shorter response time, and the Xbox registered the greatest response time on idle and gravel terrain. There was no significant difference between controllers on cross-country terrain.

A post hoc test on the terrain data indicated that elapsed time was significantly greater on cross-country terrain (7.99 ± 4.48 s) than on gravel (5.74 ± 4.48 s) or idle (5.78 ± 4.48 s) terrain. There was no significant difference between gravel and idle terrain.

As can be seen in figure 7, an analysis of controller main effect data is precluded by the data; the relationship between controllers for cross-country conditions is different from those for idle and gravel conditions.
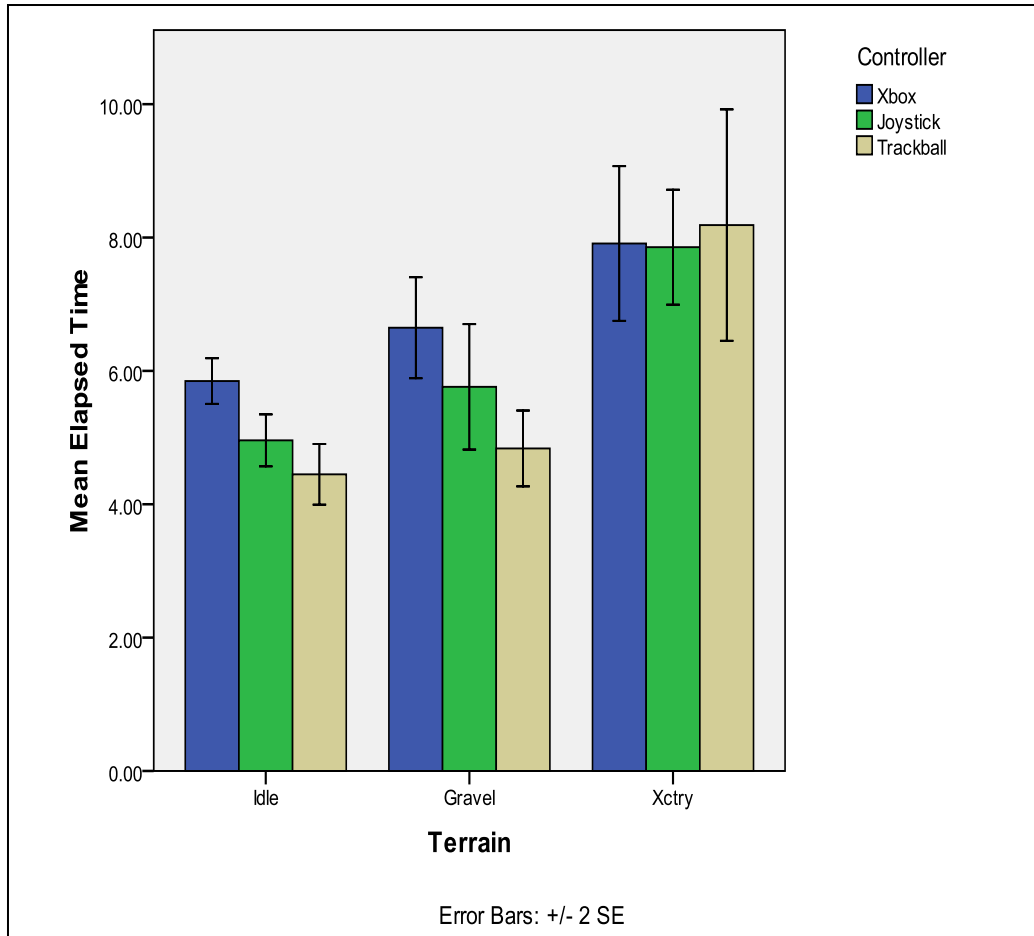
Figure 7. Mean drag-and-drop elapsed response time (seconds) for the terrain x controller interaction.

4.2.2 Number of Background Clicks

The number of background clicks is an error measure, signifying the number of incorrect clicks made on nontarget objects. The data indicated that out of 1166 trials, 198 (17%) were characterized as background clicks. Because this is a small sample size, a nonparametric Kruskal-Wallis test for significant differences between means was conducted to determine whether terrain and/or controller had a significant effect on the number of background clicks.

For terrain type, there were 29 background clicks at engine idle, 71 on gravel terrain, and 98 on cross-country. However, the Kruskal-Wallis test indicated that there was no significant difference ($p > 0.05$) for terrain type.

For controller type, the Xbox had 35 background clicks, the joystick had 44, and the trackball had 119. The Kruskal-Wallis test indicated that there was a significant difference ($p = 0.029$) for controller type. The post hoc median test indicated that the trackball had a significantly greater number of background clicks than the other two controllers, and that there were no other significant differences.

4.2.3 Number of Missed Drags

The number of missed drags is an error measure signifying the number of drags missed. The data indicated that out of 1166 trials, 128 (11%) were characterized as background clicks indicative of a missed drag.

For terrain type, there were 26 background clicks at engine idle, 52 on gravel terrain, and 50 on cross-country. However, the Kruskal-Wallis test indicated that there was no significant difference ($p > 0.05$) between means for terrain type.

For controller type, the Xbox had 16 background clicks, the joystick had 46, and the trackball had 66. The Kruskal-Wallis test indicated that there was a significant difference ($p = 0.032$) for controller type. The post hoc median test indicated that the joystick and trackball had a significantly larger number of background clicks than the Xbox. There were no other significant differences.

4.3   Point-To-Point

4.3.1 Mean Response Time to Select

The ANOVA performed on the mean time to select point-to-point targets data indicated significant interaction effects for terrain x controller (F = 9.18; p = 0.00) and significant main effects for terrain (F = 19.03; p = 0.00) and controller (F = 32.85; p = 0.00). Results from the post hoc test for the terrain x controller interaction are shown in figure 8. Data indicated that on idle terrain, all means were significantly different; the trackball provided significantly lower mean time to select and Xbox the highest. On gravel terrain, the trackball again provided significantly lower mean time to select, while the joystick and Xbox were significantly greater, but not significantly different from each other. On cross-country terrain, there was no significant difference between controllers, although the mean response time to select was significantly greater for all controllers than any other condition.

Figure 9 shows data for the terrain main effect. The mean response time to select was significantly greater for cross-country terrain than either idle or gravel. There was no significant difference between idle or gravel terrains. For controller type, the nature of the interaction (changes in the relationship between Xbox and joystick) across terrains precluded interpretation of controller main effects.
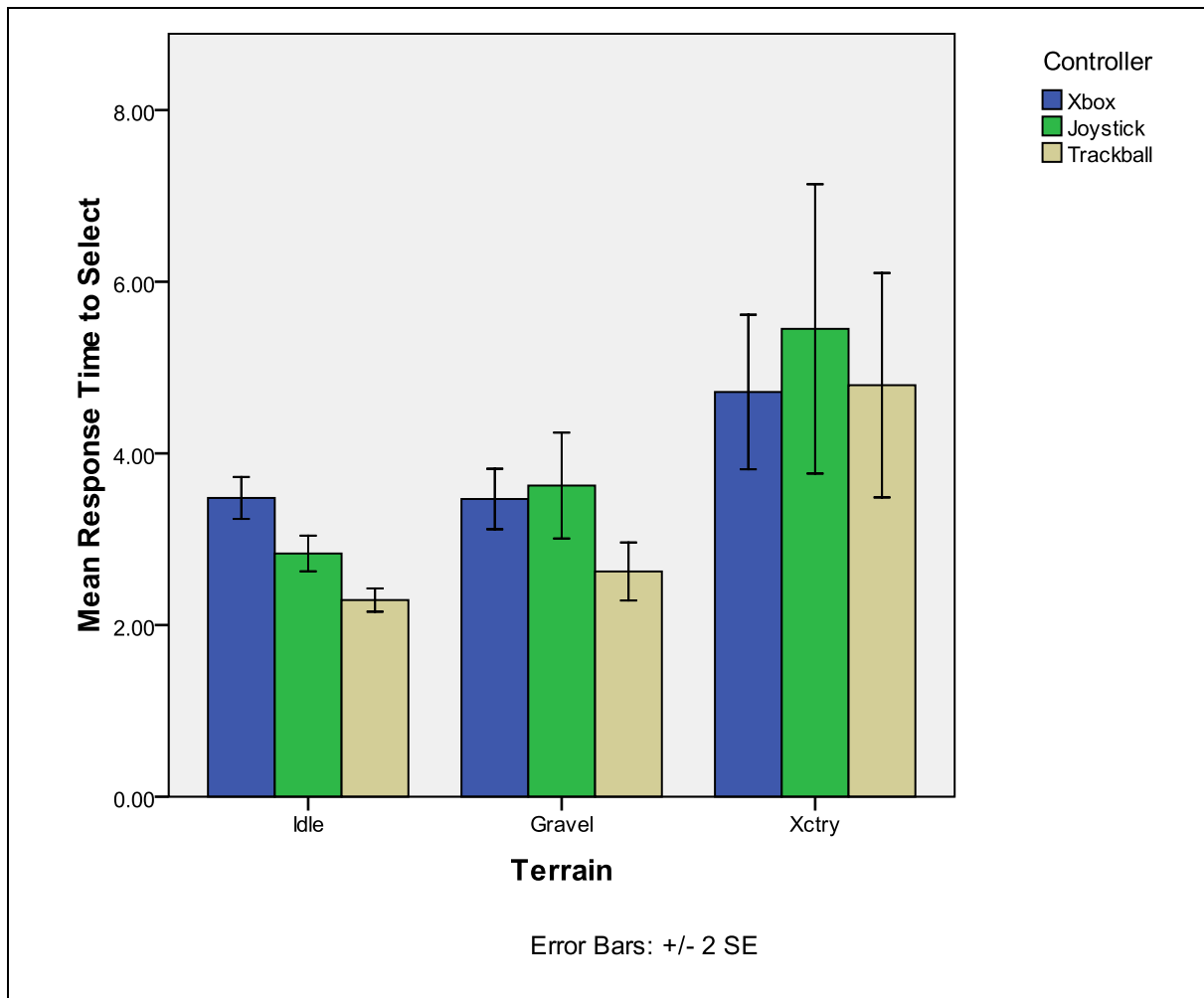
Figure 8. Mean response time (seconds) to select for the terrain x controller interaction, point-to-point time to select.
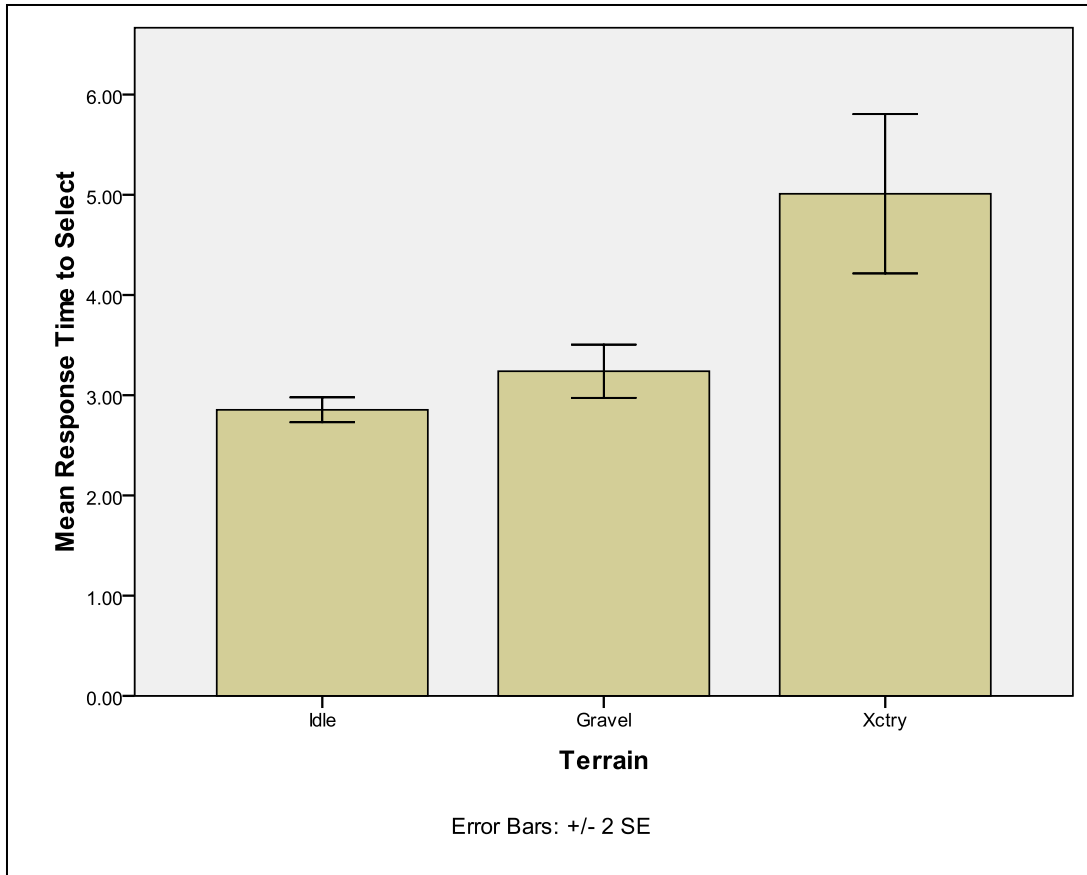
Figure 9. Mean response time to select (seconds) for terrain, point-to-point time to select.

4.3.2 Mean Response Time to Delete

The ANOVA performed on the transformed data indicated significant interaction effects for terrain x controller ($F = 5.64$; $p = 0.00$), and significant main effects for terrain ($F = 27.96$; $p = 0.00$) and controller ($F = 41.61$; $p = 0.00$). The means for the terrain x controller data are shown in figure 10. Post hoc results indicated that the trackball provided a significantly shorter mean time to delete across all terrains. For the gravel and cross-country terrains, there was no significant difference between the joystick and the Xbox, though each was greater than the trackball. For the idle condition, the joystick had a significantly shorter mean time to delete than the Xbox. The mean response time to delete ranged from ~4.5 to 10.0 s. Whether these differences could make a practical difference in U.S. Army mobile operations would depend upon the particular operation and mission being performed. All controllers had a significantly greater mean response time to delete on cross-country terrain, while there was no significant difference between idle and gravel terrain.
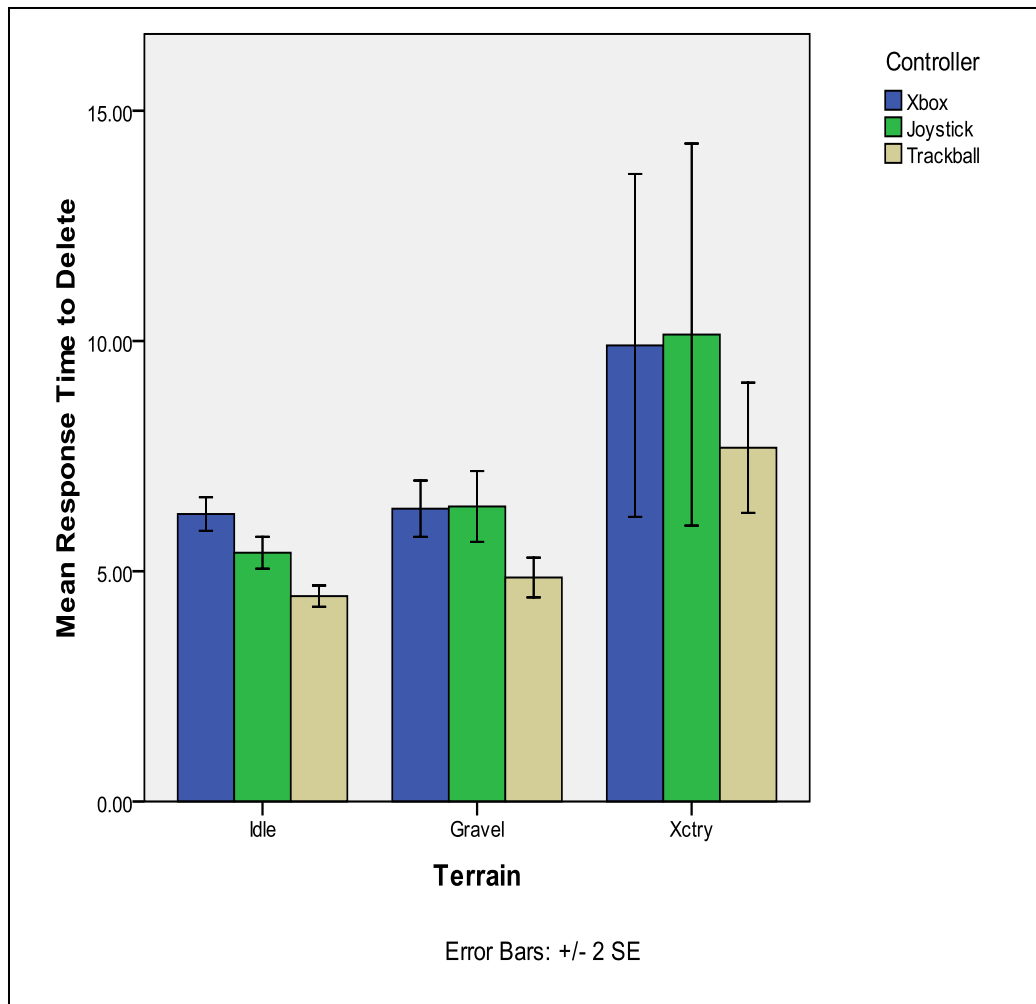
Figure 10. Mean response time (seconds) to delete for the terrain x controller interaction.

Figure 11 shows data for the terrain main effect. The mean response time to delete was significantly greater for cross-country terrain than either idle or gravel. There was no significant difference between idle or gravel terrains. For controller type, the nature of the interaction (changes in the relationship between Xbox and joystick) precluded interpretation of controller main effects.
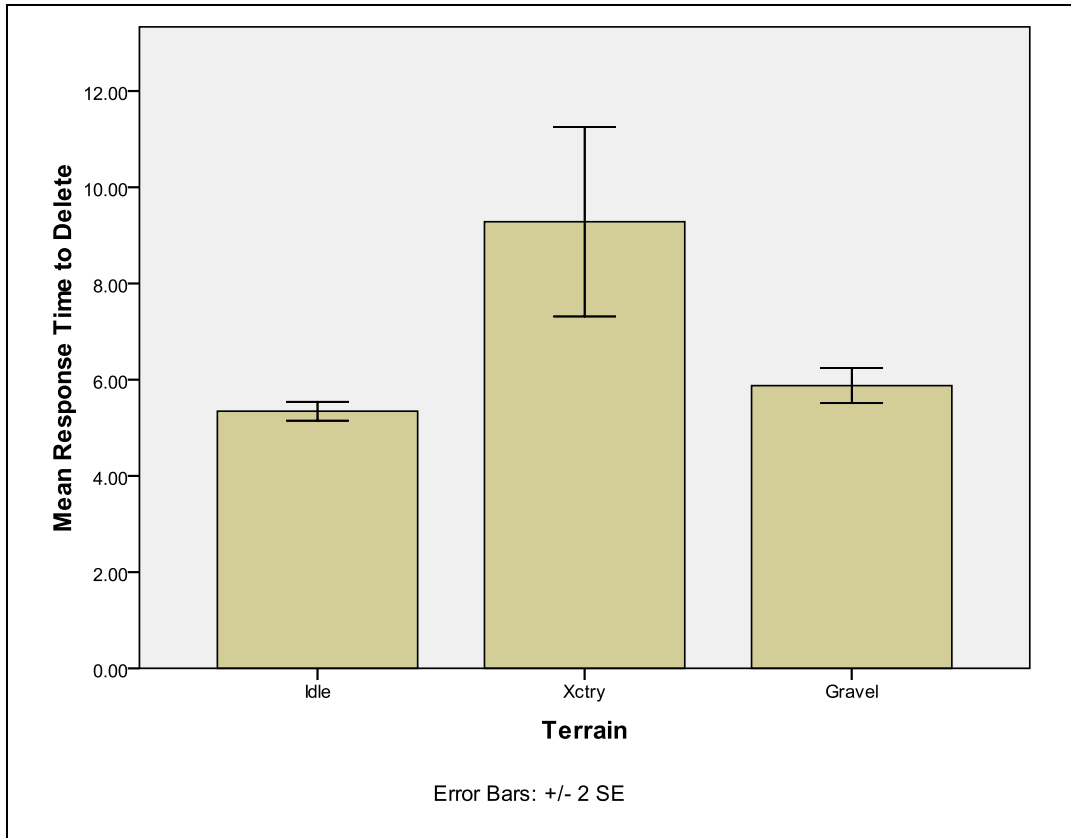
Figure 11. Mean response time (seconds) to delete for the terrain.

4.3.3 Mean Number of Background Clicks

The number of background clicks is an error measure, signifying the number of incorrect clicks made on nontarget objects. The mean number of background clicks data indicated that out of 1166 total clicks, 169 (14%) were characterized as background clicks.

For terrain, 35 background clicks were performed at engine idle, 39 on gravel, and 95 on cross-country. The Kruskal-Wallis test indicated that there was there was a significant difference ($p = 0.033$) for terrain type. The median test indicated that the number of background clicks on cross-country terrain was significantly higher than those at engine idle and on gravel terrain.

For controller, 66 were performed with the Xbox, 62 with the trackball, and 41 with the joystick. The Kruskal-Wallis test indicated that there was there was no significant difference ($p > 0.05$) for controller.

4.4 Text Select

4.4.1 Time to Select

The ANOVA performed on the transformed data indicated significant main effects for controller ($F = 32.62$; $p = 0.00$) and terrain ($F = 11.39$; $p = 0.00$), with no significant interaction.

The controller data, as shown in figure 12, indicated that the mean time to select text was significantly shorter for the trackball than for the Xbox and the joystick, with no significant difference between Xbox and joystick.
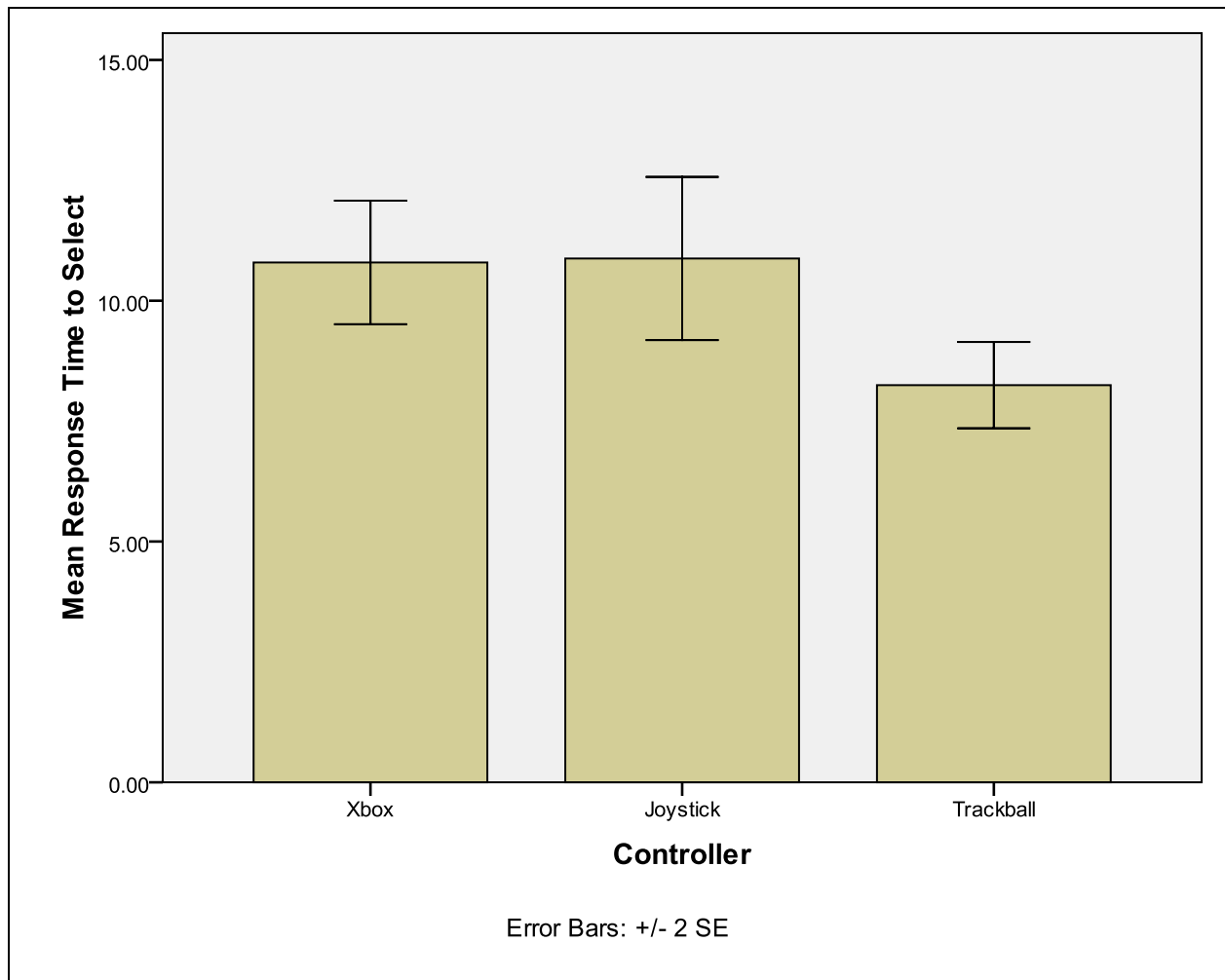

Figure 12. Mean response time to select for controllers.

The post hoc data for terrain, shown in figure 13, indicated that mean time to select was greatest for cross-country terrain, shorter for gravel terrain, and shortest for engine idle conditions. All means were significantly different.
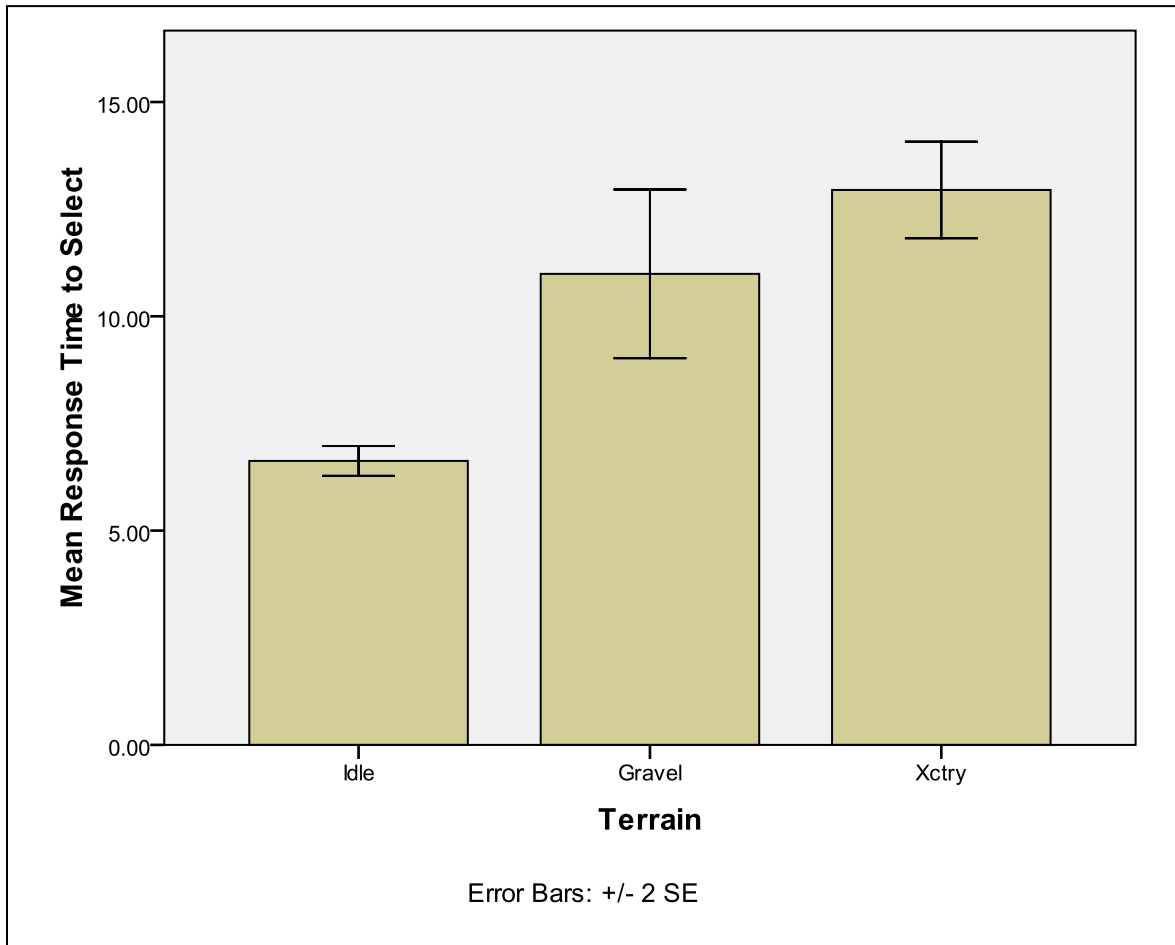
Figure 13. Mean response time to select for terrain.

4.4.2 Number of Text Select Errors

The error data indicated that out of 1060 total text select clicks, 185 (17%) were characterized as errors. For terrain, 37 text select errors were made on gravel terrain, 46 at engine idle, and 102 on cross-country terrain. The Kruskal-Wallis test indicated that there was there was no significant difference ($p > 0.05$) for type of terrain.

For controller, 51 errors were made with the Xbox, 61 with the joystick, and 73 with the trackball. The Kruskal-Wallis test indicated that there was there was no significant difference ($p > 0.05$) for type of controller.

4.5 Workload

The ANOVA performed on the workload data indicated significant main effects for terrain ($F = 160.94$; $p = 0.00$). There were no other significant main effects or interactions. The mean workload rating (higher numbers indicate greater workload, with 10 being the upper limit) indicated that perceived workload was greater for cross-country terrain (6.31) than for gravel (4.35) or idle (3.33) conditions. Each mean was significantly different. This indicated that participants regarded workload as being greatest on cross-country terrain and least at engine idle. Unfortunately, the data collected on motion sickness was inadvertently destroyed.

5. Discussion

The primary objective of this study was to determine the usability of three different computer game control devices (trackball, joystick, and Xbox controller) for Army HRI tasks performed in a moving Army vehicle. The second objective was to determine the extent to which vehicle operation in different conditions (baseline engine idle, gravel roads, and cross-country terrain) affects the usability of the different controllers.

5.1 Controller

The hypothesis stated that the Xbox controller would provide a performance advantage over the joystick and trackball on cross-country terrain because the hand-held Xbox would enable more efficient controller manipulation. Time data indicate that this hypothesis was not supported. For the few tasks that did have a significant controller main effect, different controllers were found to provide the best performance.

Analysis of click and hold timing measures showed a significant main effect for controller, with the shortest time for trackball and no significant difference between the Xbox and joystick. For click and hold number of clicks, the joystick provided the best performance (a smaller mean number of clicks), with no significant difference between the Xbox and trackball. For text select time-based measure (time to select text), the trackball showed a significantly shorter response time than for the Xbox and joystick, with no significant difference between the latter controllers.

For error-based measures, the Xbox provided an advantage in performance. For drag and drop number of background clicks and number of missed drags, the Xbox had the smallest number of errors and the trackball had the greatest number of errors. However, for the point-to-point task, the greatest number of errors was logged with the Xbox and the trackball, and the least number with the joystick.

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Together these results indicate that the Xbox controller, while not providing the best time data, did have an advantage in error-based measures on tasks that involved holding a selection button while at the same time moving the cursor.

5.2 Terrain

The hypothesis was that terrain types with greater surface variation would have a more significant effect on controller performance in Army-based HRI tasks. As a result, it was hypothesized that cross-country terrain (0.292 total RMSA acceleration) would produce the greatest decrement in Soldier performance, followed by gravel (0.182 total RMSA acceleration) and then idle (0.053 total RMSA acceleration). The data for all tasks support the hypothesis regarding cross-country terrain, and all tasks showed the greatest decrement in cross-country terrain. However, differences between gravel and engine idle conditions depended on the particular task.

Analysis of click and hold, drag and drop, point-to-point, and text select timing measures (e.g., mean elapsed time to perform the task for click and hold and drag and drop; time to select for point-to-point and text select; and mean time to delete for point-to-point) indicated that cross-country terrain required the greatest time to perform the task measures. Some timing measures (click and hold, text select), indicated that gravel terrain resulted in a significantly greater time to perform the task than engine idle conditions, while other tasks (drag and drop, point-to-point) showed no significant difference between gravel and idle terrains.

For error measures such as number of background clicks, there was a significantly greater number of errors for controller type (trackball) for drag and drop, while terrain (cross-country) had a significantly greater number of errors for point-to-point. For drag and drop missed drags, the joystick and trackball controllers had a significantly greater number of errors than the Xbox. There were no other significant effects in any of the error tests.

Workload data also provided information regarding terrain effects. Participants indicated greater perceived workload ratings for cross-country terrain than for gravel or idle conditions, with each condition significantly different.

Together these results indicate that as ride quality deteriorated with greater terrain surface variation, the operator's performance using all of the controllers declined.

5.3 Interaction Between Terrain and Controller

As previously noted, there were several significant interaction effects between terrain and controller for different tasks. For time-based drag and drop (mean elapsed time) and point-to-point (mean response time to select) tasks, the trackball provided a significantly shorter response time on idle and gravel terrain, and there was no significant difference between controllers on cross-country terrain. For drag and drop, the Xbox provided the longest response time on idle

and gravel terrain. For point-to-point mean time to select, the Xbox provided a significantly longer mean response time on idle terrain. On gravel terrain, the joystick and Xbox had the longest response times, but were not significantly different from each other. For point-to-point mean time to delete data, the trackball provided a significantly shorter time to delete across all terrains. For gravel and cross country terrains, there was no significant difference between the joystick and the Xbox. For the idle condition, the joystick had a significantly shorter mean time to delete than the Xbox.

5.4 Issues of Interest

One may question why the Xbox controller did not show a significant difference in error and time performance over the other two controllers on cross-country terrain. The Xbox was hypothesized to have a performance advantage over the joystick and trackball in a moving environment because it is held in the hands, which was thought to provide more of a reference point to enable users' thumbs and fingers to manipulate the controls more efficiently than with the other controllers. However, experimenter observations during the study indicated that participants used different strategies to attempt to stabilize each of the controller types. Since the participants were not restricted in their method of controller use, they developed different mechanisms to enable moving small effectors instead of large limbs to increase the functionality of each device in the moving environments. Participants were observed holding the Xbox close to their body with their hands, especially during trials on cross-country terrain. Users were observed attempting to stabilize the joystick by positioning it on the upper leg or between their legs. Users attempted to stabilize the trackball by holding the unit to the surface of the shelter with one hand, and using the dominant hand to move the trackball. In general, we argue that because users were able to find a way to stabilize each type of controller, the Xbox did not have a performance advantage.

Another issue deals with the relevancy of the difference in time for terrains. In many instances, although some differences were significant, they were relatively small (i.e., differences between the highest and lowest response time means across terrains was 2.11 s for click and hold, and 2.25 s for drag and drop). Whether these differences would have an effect on U.S. Army mobile operations would depend upon the particular operation and mission being performed.

5.5 Future Research

Although this research shows that the gaming console may have some advantages over traditional computer input devices (joystick and trackball), additional work is needed to understand comparative advantages and disadvantages of various control devices for various tasks performed within moving vehicles. Future research could also explore the use of the yoke and touchscreen as control devices. Future research should target a population with known gaming experience and experience with handheld controllers. This would be more relevant to the population of the young Soldiers that would be the projected users of such systems.

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